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Correspondent: Vasken Hagopian
Department of Physics
Florida State Universit
Tallahassee, Fla. 3230

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NAL BUBBLE CHAMBER PROPOSAL

SEARCH FOR FRACTIONALLY CHARGED PARTICLES

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ABSTRACT

Search for fractionally charged particles of charge ze with z in the range of $\frac{1}{4}$ to $\frac{3}{4}$. Production is through collisions of the primary proton beam (200 GeV or higher) with nucleons in a target. The detection method is a hydrogen bubble chamber where fractionally charged particles in the beam will have an ionization less than minimum defined for $z = 1$. We propose an exposure of 10,000 pictures with a negatively charged beam and 10,000 pictures with a positively charged beam, both unseparated.

INTRODUCTION

The search for the quark, or fractionally charged particle has been going on for many years. There is even some evidence, although not completely convincing, that quarks of charge $z = \frac{2}{3}$ might exist. There is no point in discussing here the theoretical aspects of this proposed search, as the subject has been widely discussed elsewhere. If such fractionally charged particles exist, they are almost certain to have a mass greater than 5 GeV.[1] If so, then the primary mechanism of creating such particles with maximum phase space will be the creation of a quark-antiquark pair. The maximum mass quark that can be produced in the reaction $pp \rightarrow q\bar{q}\, pp$ by 200 GeV protons is about 8.8 GeV.

One of the best methods of detecting quarks is by observation of less than "minimum" ionizing particles in a beam using a bubble chamber filled with liquid hydrogen. There are several advantages to this method of observation. Hydrogen bubble chambers do not have the relativistic rise in ionization that occurs in heavy-liquid chambers. That all beam particles will have the same "age" can easily be verified by counters in front of the chamber. If such a particle is observed, it will be permanently displayed on the film and will be hard to dismiss as malfunction of equipment, or as possible noise as in counter experiments. We need only one good less-than-"minimum" track for proof of existence of particles with charge less than one. If such a track is observed, the probability of forming a visible delta ray (i.e., electron recoil) is quite good, the actual number being proportional to z^2 and length of the bubble chamber. A lower than "minimum" ionizing beam particle forming a normal "minimum" ionizing delta ray will be an absolute proof of the existence of fractional charges less than one.

During 1964 when the first search for fractionally charged particles started, one of us (V. H.) proposed and performed such an experiment at the AGS with the 80" chamber. A copy of the final report is included at the end of this proposal where the details of the previous experiment are given. In that experiment and also other similar ones the lower mass limit was determined to be 2.5 GeV or so. Another negative experiment recently performed at Serpukov raised this lower mass limit to about 5 GeV. In this proposal we plan to extend the search to the highest possible mass that can be produced at NAL, about 8.8 GeV or so.

Some Physics Details

Even though the nucleon can be broken into 3 quarks, the most favorable way of making massive fractionally charged particles is by particle-antiparticle pair production. Only one of the quarks need be stable, and if the lifetime of the others is extremely short, then it is possible that only the stable one could be observed. From SU_3 considerations, the quark of charge $z = \frac{2}{3}$ will have the lowest mass. It is very hard to estimate possible cross sections, but we could compare with the anti-proton cross section which is about 1% of pion production at forward angles. In 10,000 pictures with 20-25 beam tracks, we would have about 200,000 to 250,000 particles entering the chamber. In the negatively charged beam, where most of the particles will be pions, even if the yield of quarks is a thousand times smaller than the yield of antiprotons, we should be able to observe it. In the positive beam portion of this experiment, where $\frac{1}{3}$ to $\frac{2}{3}$ of the beam could be protons, depending on the angle of production and beam momentum, the detection of positively charged quarks should correspond to a yield 300-1000 times smaller than that of anti-protons.

In a conventional unseparated bubble chamber beam, the momentum of fractionally charged particles will be only zp, where p is the momentum of unit charged particles. In order to enhance phase-space, the largest possible p will be the best for observing quarks. In reality, if it were possible to tune the beam to a slightly higher momentum than kinematically possible for unit charged particles, such as pions, then the only particles that would arrive at the chamber would be those with momentum ze where $z < 1$. This condition would be nice to have, but it is not necessary.

The 10,000 pictures with the negative beam could also be used to study $\pi^- p$ interactions at the highest tuneable momentum. Although the number of pictures is small, some partial cross-sections could still be determined.

A priori we have no reason to believe that a positively charged beam would be better for detecting quarks. In reality the background, i.e. singly charged particles, is smaller when using a negative beam than a positive one due to the large number of protons in the positive beam. So our higher priority will be the negative beam exposure but since so much is unknown in this field, we still would like to request beams of both charges.

Some Experimental Details

For this experiment we need a hydrogen bubble chamber with an unseparated tuneable beam. The portion of the primary proton beam necessary for this experiment should be less than 1% of the available intensity. The number of beam particles per picture will depend on the chamber available; almost any chamber is satisfactory for this experiment. We will supply more details when it is better known what kind of chamber and beam are available.

This is essentially a scanning experiment and results should be known within a few weeks after obtaining the developed photographs.

We have included a copy of the final report (Phys. Rev. Let. 13, 280 (1964)) from our previous bubble chamber quark search at the AGS at the end of this proposal. The techniques to be used are essentially the same as those described in the Phys. Rev. Let. report.

Staff

For this proposal, the staff needed is very small, but we will take this opportunity to acquaint you with our present operations at the Florida State University. At present our experimental group is composed of four faculty members, 2 research associates and one staff physicist, all Ph.D.-level with bubble chambers as our specialty. In addition we have three theoretical elementary particle physicists on the faculty who work very closely with the experimentalists. As of June 1970, we have five experimental graduate students; we expect this number to remain fairly constant.

As more information, we add that at FSU the total operating budget is now about $600,000 per year -- one quarter of which is support from the AEC. A major share of the University's contribution ($250,000) is free computer time on the FSU CDC 6400.

There are ten full-time equivalent scanner-measurers, one full time electronics engineer, and 1.5 full-time-equivalent electronics technicians. The equipment at FSU as of June 1970 consists of two image-plane digitizers, two film-plane measuring devices, two scanning machines, and two more image-plane digitizers under construction. We also have an EMR 6050 computer which is being connected on-line to the image-plane digitizers.

REFERENCES

1. (a) V. Hagopian et al. Phys. Rev. Letters 13, 280 (1964). A copy of this report is included at the end of this proposal.

   (b) Antipov et al. Institute for High Energy Physics, Serpukhov, USSR, Phys. Letters, 30B, 576 (1969). In this experiment using negatively charged beam, the minimum possible mass of the quark was determined to be 5 GeV.

   (c) There are two reports of possible quarks in air showers of charge $\frac{2}{3}$ reported in the literature, both inconclusive. I. Cairns, C. McCusker, et. al., Phys. Rev. 186, 1394 (1969) and Chu, et.al. Phys. Rev. Letters, 24, 917 (1970).

FURTHER SEARCH FOR FRACTIONALLY CHARGED PARTICLES*†

V. Hagopian, W. Selove, R. Ehrlich, E. Leboy, and R. Lanza
University of Pennsylvania, Philadelphia, Pennsylvania

and

D. Rahm and M. Webster
Brookhaven National Laboratory, Upton, New York
(Received 3 August 1964)

Recent theoretical works by Gell-Mann[1] and Zweig[2] have suggested the possible existence of fractionally charged particles, with magnitudes $\frac{1}{3}$ and $\frac{2}{3}$ in units of the electron charge, as an esthetically appealing representation of SU(3) triplets. Several unsuccessful searches for these fractionally charged particles have been reported both for strongly interacting particles of charges $-\frac{1}{3}$ and $-\frac{2}{3}$, and for weakly interacting particles of charges $\pm\frac{1}{3}$, for masses up to 2.2 BeV[3] or somewhat higher.[4] Here we report a further unsuccessful search for positive fractionally charged particles, of charge $\frac{1}{3}$ or $\frac{2}{3}$, lifetime greater than 10^{-7} sec, and masses as high as about 2.5 BeV (for charge $\frac{1}{3}$) or 3.0 BeV (for charge $\frac{2}{3}$).

We used the 80-in. BNL liquid-hydrogen bubble chamber, and an unseparated beam of positive secondaries, at the AGS. The momentum of the internal circulating proton beam of the AGS before striking a tungsten target was 31 BeV/c. The secondary beam had a direction of 120 mrad with respect to the circulating proton beam and was tuned to 8.5 BeV/c for particles of unit electric charge. About one third of the secondary particles were π^+ mesons and the rest mostly protons. 10 000 pictures were taken with an average of 30 tracks per picture, corresponding to 100 000 π^+ at 8.5 BeV/c. No particles of charges between $\frac{1}{4}$ and $\frac{3}{4}$ were found. From available data on secondary beams at the AGS,[5] the sensitivity of this experiment was calculated to be better than one particle of charge $\frac{1}{3}$ in 6×10^{8} π^+ at 2.83 BeV/c and one particle of charge $\frac{2}{3}$ in 3×10^{5} π^+ at 5.67 BeV/c.

For comparison with these figures it may be noted that the antiproton intensity under the beam conditions used is about 1%, relative to π's of the same momenta.

If the production mechanism for making the fractionally charged particles is pair production of a particle-antiparticle pair, then the highest masses that could be formed in this experiment would be about 2.5 BeV for charge $\frac{1}{3}$ and about 3 BeV for charge $\frac{2}{3}$. These mass values include a rough estimate of the effect of the "Fermi" motion of the nucleons in the target. Our conclusion is that if particles of charge ze with z in the range of $+\frac{1}{4}$ to $+\frac{3}{4}$ exist, and if they are produced in pairs with production matrix element similar in magnitude to that for nucleon pairs, then either the lifetime is shorter than about 10^{-7} sec or the mass is greater than 2.5 to 3.0 BeV, depending on the magnitude of z.

Since this experiment, sensitive to positive particles, and other similar ones, sensitive to negative particles,[3,4] had similar mass and lifetime sensitivities, and since, if fractionally charged particles exist, at least one of them must be absolutely stable, we conclude from the combined results of the experiment that, with no lifetime limitation, no strongly interacting fractionally charged particles of charge $\frac{1}{3}$ or $\frac{2}{3}$, with mass up to about 2.5 BeV, are produced in proton-nucleus collisions at about 30 BeV.

The remainder of this note gives some further reasons for the choice of the experimental conditions and some further experimental details.

In this experiment, the most favorable way of making massive fractionally charged particles is by particle-antiparticle pair production. If the mass of these fractionally charged particles were about that of a nucleon or less, then breaking a nucleon into three of these particles would be en-

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ergetically more favorable and might dominate. In Gell-Mann's[1] notation, the process in this case would be

$$p+p \to p+u+u+d$$

and

$$p+n \to p+u+d+d,$$

where u has charge $+\frac{2}{3}$, baryon number $\frac{1}{3}$, and strangeness 0; and d has charge $-\frac{1}{3}$, baryon number $\frac{1}{3}$, and strangeness 0. If d had a short lifetime then the only observable fractionally charged particle, in experiments of this type, might be the u, with charge $+\frac{2}{3}$. Previous experiments[3,4] were not sensitive to this charge value; that fact was one motivation for the present experiment.

This experiment used the existing facilities of the 80-in. chamber and beam. The maximum momentum to which the beam could be tuned was 8.5 BeV/c, although a higher beam momentum would have been more favorable.

Fractionally charged particles would have been detected through the expected lower bubble density relative to ordinary "minimum ionizing" tracks, and would have been unambiguously identified by observation of a low-density beam track with an ordinary-density delta ray.

Spurious low-density tracks could be produced by "early" tracks, passing through the chamber before the chamber was fully sensitive. To avoid this background the AGS beam was deflected onto the target by a rapid beam deflector. Except for occasional particles, the duration of the "beam spill" was about 100 microseconds, and all particles passed through the chamber within a stable time period relative to the beam deflecting pulse. To eliminate the occasional early particles, two methods were used. First it was observed experimentally that particles that entered the chamber from 5 to 1.5 milliseconds before the main pulse left tracks of lower bubble density. To eliminate these troublesome early particles, an electronic gate was built to last from 10 to 1 milliseconds before the main beam pulse. If any particle came during this gate "on" time, the chamber light was not flashed on and no picture was taken. To check on the performance of the gate, we also used the system employed by Morrison.[4] With every beam pulse a cathode-ray oscilloscope was photographed showing the time distribution of the particles entering the chamber during the interval from 10 milliseconds before the main beam pulse up to the main beam pulse. As a final check, low-density tracks were carefully examined for delta rays. A delta ray having bubble density similar to that of the track from which the delta ray came identifies the parent track as an "early" track and not a fractionally charged track. This check was very sensitive because on the average a beam track of unit charge had two delta rays of measurable bubble density, in this experiment.

The film was scanned twice by physicists and scanners. 16 low-density tracks were found (evidently having failed to give a signal in the scintillation detectors for the gate-and-oscilloscope system), but were identified as early tracks. 14 had delta rays of low bubble density. The other two had no measurable delta rays (this is about the number of low-density tracks, compared to the other 14, that would be expected not to have delta rays); these two could also be identified unambiguously as early tracks by virtue of having larger (and therefore older) bubbles than all other tracks in the same pictures.

We would like to thank the operation staff of both the AGS and the 80-in. hydrogen chamber. Also our thanks go to H. Brody, H. Yuta, M. Bloom, and S. Ford for helping with this experiment.

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